43D CONGRESS, 1st Session. } HOUSE OF REPRESENTATIVES. { Ex. Doc. No. 265.

EXTENSION OF THE CHESAPEAKE AND OHIO CANAL.

LETTER

FROM

THE CHIEF CLERK OF THE WAR DEPARTMENT,

IN ANSWER TO

A resolution of the House of June 9, 1874, in relation to the extension of the Chesapeake and Ohio Canal.

JUNE 19, 1874.—Referred to the Committee on Railways and Canals and ordered to be printed.

WAR DEPARTMENT, *June* 15, 1874.

The chief clerk of the War Department, in the absence of the Secretary of War, has the honor to transmit to the House of Representatives, in compliance with the resolution of the House of the 9th instant, supplemental report of the engineers on the extension of the Chesapeake and Ohio Canal, with letter of the Chief of Engineers submitting the same.

H. T. CROSBY,
Chief Clerk.

OFFICE OF THE CHIEF OF ENGINEERS,
Washington, D. C., June 13, 1874.

SIR: I have to acknowledge the reference to this office, for report, of the resolution of the House of Representatives of June 9, instant, as follows, viz: "That the Secretary of War be directed to furnish this House with the supplemental report of the engineers on the extension of the Chesapeake and Ohio Canal;" and in compliance therewith beg leave to submit a copy of the supplemental report referred to, made to this office by Maj. W. E. Merrill, Corps of Engineers, May 8, 1874.

The resolution is herewith respectfully returned.

Very respectfully, your obedient servant,

A. A. HUMPHREYS,
Brigadier-General and Chief of Engineers.

Hon. W. W. BELKNAP,
Secretary of War.

EXTENSION OF THE CHESAPEAKE AND OHIO CANAL TO THE OHIO RIVER

NOTE.—The first part of this report is printed in House Executive Document No. 208, Forty-third Congress, first session.

UNITED STATES ENGINEER OFFICE,
Cincinnati, Ohio, May 8, 1874.

GENERAL: In my report on the extension of the Chesapeake and Ohio Canal, dated March 20, 1874, and printed as Executive Document No. 208, House of Representatives, Forty-third Congress, first session, I stated, under the heading "Inclined Planes," that Colonel Sedgwick was preparing a special paper on the method of canal navigation by the use of inclined planes, which I intended to forward with the request that it might subsequently be attached to my report. I have just received the paper in question, and I herewith forward it, with the request that it may also be transmitted to Congress for publication. The subject discussed is one whose details are not widely known, and the information which the report contains will be quite useful to all engineers who have to discuss the problem of canal navigation in mountainous districts.

Respectfully, your obedient servant,

WM. E. MERRILL,
Major Engineers.

Brig. Gen. A. A. HUMPHREYS,
Chief of Engineers, Washington, D. C.

WASHINGTON, D. C., *March* 30, 1874.

COLONEL: In relation to the extension of the Chesapeake and Ohio Canal from Cumberland, Md., to Pittsburgh, on the Ohio, I have the honor to make a supplemental report upon the study of "inclined planes" as a means of raising and lowering boats from one level of a canal to another, instead of the canal lift-locks.

The use of such planes is not new, although they are somewhat of a novelty. They have been in use on the Duke of Bridgewater's Canal, in England, and planes carrying caissons full of water in which the boats were floated have been used on the Monkland Canal, near Glasgow, Scotland; but the most noted and, doubtless, the most successful application and use of inclined planes is a matter of national pride to the United States, in the example of their efficiency and economy in cost, and saving of time in transportation, as used on the line of the Morris Canal, in New Jersey.

The Morris Canal extends across the northern portion of New Jersey, from Easton, Pa., on the Delaware River, to tide-water at Newark on the Bay of Newark, a distance of one hundred and one miles. The total rise and fall on the canal is stated at 1,557 feet, of which 223 feet is overcome by locks of various lifts and 1,334 feet by inclined planes, averaging 58 feet lift each, of which one, near the western terminus of the canal, has a height of 100 feet.

These planes were, when first constructed, operated in connection with an ordinary lift-lock placed at the head of the plane, connected with the upper level or pool, into the bottom of which lock the track (an ordinary railway-track) of the plane was laid, and led down the plane to the lower pool. The boats were carried up or down the plane on a wheeled carriage running on a railway-track operated by an endless-chain passing around large horizontal pulleys (fixed at the head and foot of the plane) and attached to a large winding drum operated by a turbine motor, and the usual gearing and machinery for transmitting such power. The turbine with its machinery is located in a house on one side of the plane at about the middle of its length, and is operated by the head of water taken from the upper pool. The boats were taken into the locks at the head of the planes in the usual manner, and as the prism of lift-water was discharged the boat settled down into the carriage and was let down the plane to the lower pool, where the boat, following the inclined plane to a depth greater than the draught of the boat, floated and was detached, passing on its way. Boats moving in the contrary direction were drawn over the carriages as they stood in the lower pools at the foot of the planes and made fast thereto, and the machinery being put in motion, the carriage rising along the planes, the boats settled down upon them and were carried up to the head of the planes and into the locks, which were then closed, the prism of lift-water let in, and the boats were raised to the upper pool and passed on their way.

The locks at the heads of the planes have been taken away, and the railways of the planes are carried over into and down to the bottom of the upper pools, where the boats are received and discharged from the carriages in the same manner as at the foot of the planes in the lower pools. This arrangement of the two planes is called a "*summit-plane*," and this is the kind of plane I have considered in connection with the extension of the Chesapeake and Ohio Canal, with special reference to their application on the mountain section of the Savage River route, between the mouth of Savage River and Salisbury, on the Castleman River, and at one or two places farther west on the route where their usefulness is apparent.

The loaded boats of the Morris Canal, together with the carriage, weigh about 110 tons. Observations made on the operating of a plane at Newark, rising one foot in ten, and having a lift of 70 feet, showed that boats were readily and efficiently passed from one pool to the other, over a horizontal distance of about 1,000 feet, in four minutes, equal to a rate of 28 miles per hour.

Description and estimate of cost.

The accompanying drawings showing a profile and plan of a single-track plane, and a plan of a double-track plane, illustrate the arrangements and dimensions of a summit-plane of 64 feet lift, rising one foot in 10 feet. H is the upper and L the lower pool or level on canal, connected by the inclined plane. The summit of the plane at S is from 1½ to 2 feet higher than the surface of the upper pool, and the second branch of the plane descends to the bottom of the upper pool at the rate of 1 foot in 10 feet, and the foot of each plane is continued beyond the ordinary depth of the canal to gain depth enough to allow the carriage to pass under the boat as it floats, as shown at A. The additional depth shown in this plane is about 6 feet, requiring a total depth of 12 feet. P and P are the horizontal pulleys around which the traction cable passes connecting the carriage with the winding-drum D. They are *firmly* fixed to masses of masonry. The turbine motor, connecting with the winding-drum by suitable gearing, is placed in a suitable house at the foot of the plane to utilize the available hydraulic head between the pools.

The carriage is formed of two parallel trusses, each resting on two trucks of two iron wheels, each flanged like ordinary railroad car-wheels. The trusses are connected by bearing joists or floor beams on which the boats rest while being moved up or down the plane. The trusses are carried by bolsters resting on axle-pivots at O O in such manner that the trucks may, in moving over the crest of the plane, adjust themselves to the plane of the track by turning about the axle-pivots. The track upon which the carriage runs consists of the ordinary T railroad rail laid on longitudinal stringers, which are placed on a foundation wall of masonry, put deep enough in the ground to be undisturbed by the freezing of the ground in winter. The traction cable C is supported on grooved carrying wheels placed at proper intervals, and iron rollers are used to carry the cable over the crest of the plane. The carrying-wheels placed between the drum and the horizontal pulleys move horizontally on their axles, adapting themselves to the horizontal motion of that portion of the cable as it winds off or on the drum. The planes are increased in length in proportion to the depth reached in each pool, and a portion of level track is laid in each pool for the carriage to rest on when receiving or discharging a boat, the pulleys being placed at the ends of the level portion of track.

The total height of the main plane from the bottom of the lower pool to its crest or summit is 77.5 feet, and the height of the plane in the upper pool is 13.5 feet. The horizontal lengths of the planes are therefore 775 feet and 135 feet, and their slope lengths are 778.86 and 135.67 feet, which, together with two level portions of 100 feet each, makes the track needed 1,114.5 feet long. [Fifteen feet are taken from each end, leaving 1,085 feet of track.]

The length of cable used is twice the lengths between the pulleys, measured on the planes, the circumference of one pulley, and the distance passed over by the carriage in going from one pool to the other, say 980 feet, a total length of 3,235 feet. The ends of the cable are separately fixed to the drum, and a length of cable equal to the distance passed over by the carriage is always wound on the drum. In the double-track plane the length of cable is twice the distance between the pulleys by the planes, once and a half the circumference of a pulley, the distance between the tracks, the distance passed over by the carriage, and twice the distance from the drum to the pulleys in the upper pool, in all 4,140 feet.

The gauge of the track is 18 feet, and the slopes of the canal prism, if carried to a depth of 12 feet, will not provide room enough for the single-track plane, and the necessary widening and the excavation of the prism between the pool of each plane, and the surface of the pool is considered in the cost of the single-track plane; and in the cost of the double-track plane the expense of widening to a width of 75 feet for a distance of 300 feet in each pool is included.

The expense of deepening the canal to a depth of 12 feet for a distance of 100 feet in each pool is also included in the cost of the single-track plane.

Cost of single-track plane.

Deepening pools, 2,150 cubic yards, at 40 cents	$860 00
Grading surface of plane, say 3,000 cubic yards, at 30 cents	900 00
Trenches for masonry of track, 500 cubic yards, at 30 cents	150 00
Foundation walls, 350 cubic yards, at $8 per yard	2,800 00
Track stringers, 15,000 feet, board measure, at $35 per thousand	525 00
Fastening stringers to wall, 450 pounds bolts, at 6 cents	27 00
Track rails, 80 pounds per yard, 25.8 tons, at $90 per ton	2,322 00
Joint splices, 70, at $1 each	70 00
Track spikes, 400 pounds, at 5 cents	20 00
Laying track, say	100 00
Carrying wheels and rollers, 8,500 pounds, at 5 cents	425 00
Grooved-pulleys, 5,000 pounds, at 4½ cents	225 00
Traction cable, 3,235 feet steel-wire cable, 2¼ inches, $1.65	5,337 75
Turbine diameter (in place)	1,000 00
Gearing 20 tons cast iron, at $100 per ton	2,000 00
Drum and fixtures, 2 tons, at $100 per ton	200 00
Flume and penstock, complete, with feed-gate	5,640 00
Fixing grooved pulley, (masonry and iron)	450 00
House for machinery	1,500 00
Boat-carriage, carefully figured	2,500 00
Sum of items	27,051 75
Contingencies, 10 per cent	2,705 17
Cost of plane	29,756 92

Cost of double-track plane.

Cost of single-track plane	$27,052 00
To which add the following quantities:	
Additional widening, 3,000 cubic yards, at 40 cents	1,200 00
Trenches for foundation, 500 cubic yards, at 30 cents	150 00
Foundations, track masonry, 350 cubic yards, at $8	2,800 00
Track stringers, 15,000 feet, board measure, at $35 per thousand	525 00
Stringer-fastenings, 450 pounds bolts, at 6 cents	27 00
Track rails, 25.8 tons, at $90	2,322 00
Joint splices, 70, at $1	70 00
Track spikes, 400 pounds, at 5 cents	20 00
Laying track	100 00
Grooved-pulley, (large,) 5 tons, at $100 per ton	500 00
Carrying wheels and rollers, 5,000, at 4½ cents	225 00
Traction cable, 910 feet, at $1.65	1,501 50
Fixing pulley	250 00
Boat-carriage, as figured	2,500 00
Movable carrying wheels, 2,500 pounds, at 6 cents	150 00
Sum of items	39,392 50
Contingencies, 10 per cent	3,939 25
Cost of double-track plane	43,331 75

Economy of cost as substitute for locks.

In a mountainous country, where a considerable elevation is to be overcome in comparatively short distances, and where the ordinary lift-locks must be placed in flights, so called, that is, adjacent to each other, or be placed so close together as to seriously retard navigation as to time, the pools being so short that the average usual speed cannot be acquired between the locks, (and the time lost in locking and attendant delays consume a great part of the time on the section where the locks are so close together,) or where, to avoid such loss of time, the lifts of the locks must be made so great that the requisite supply of feed-water cannot be had, (such locks being also very expensive in their construction,) the locks in either case being a principal item of the cost of the canal, as well as a continual source of delay in transportation, if there should be but one lock for each mile, the cost of locks would be but some $16,000 per mile; but if the levels of the canal, as in some well-known cases, were ten or twelve miles long, then the cost of the locks would be but some $1,500, or even only $1,000 per mile for the ordinary lifts of eight feet; on the contrary, if the canal is to be carried into a mountainous region, where the slope of the valleys must be followed at a rate of 50 or 60 feet rise per mile, requiring 6 or 8 locks per mile, their cost becomes the principal item of expense, and may reach as much as $130,000 per mile.

Considering the section of the Chesapeake and Ohio Canal between Cumberland and Connelsville, via the Savage River route, as presented in my report of January 30, 1874, we find the cost of locks between Cumberland and the mouth of Savage River equal to 28 per cent. of the whole cost of the canal, $21,000 per mile, the locks occurring at intervals of three-quarters of a mile. At the mouth of Savage River the ascent of the mountain begins, and between that point and the summit, a distance of sixteen miles, there are 140 locks, aggregating more than 75 per cent. of the estimated cost of the canal for that section.

If to avoid this high ratio of cost of lift-locks on the line of canal, we consider the substitution therefor of the single-track inclined plane as described above, we find that one plane overcomes the lift of eight locks of 8 feet each. [This lift of the plane was assumed with special regard to this section of the canal, as, in my judgment, they can be economically placed at average intervals of about one mile.] Eighteen planes would be required to overcome the elevation of the Savage River section, where there are 140 locks, and two planes for the section between the western end of the Summit Tunnel and the mouth of Piney Bend, where there are 16 locks in 6 miles. On these two sections the slopes of the hillsides are favorably conditioned for supporting the levels of the canal for such use of the planes.

The 156 locks, estimated on this section of the canal at $16,500, (with 10 per cent. contingencies,) would cost $2,574,000, while on the contrary the 20 planes would cost but $595,138.40, a difference of $1,978,861.60 in favor of the planes, equal to a saving of 76.88 per cent. of the cost of the locks, and reducing the cost of this section of the canal by 58.58 per cent. Comparing the cost of the plane with the cost of the eight locks it would take the place of, there is a difference of $102,243.08 in favor of the cost of the plane, overcoming the same height of lift by the plane, as by the eight locks, at 22.5 per cent. of the cost of the locks.

There are no natural indications that planes could be used between Cumberland and the mouth of Savage River, and the cost of supporting the levels of the canal on the hillsides might be a greater increase (in the cost of high embankments, or the crossings of lateral ravines or valleys, and high aqueducts) than would be saved by the planes of less lift than described above.

There are, however, two places on the line of the canal west of Meyer's Dale City where planes could be advantageously used. Referring to the report of the board of internal improvement, (1st subdivision, western section,) there is a reference to the Ohio Pyle Falls, where the fall is 96 feet in the distance of one mile. The cost of a plane of this height would be in addition to the cost of the 64 feet high plane, the cost of 321.6 of track and traction-cable and their accessories amounting to $3,068.45, including 10 per cent. contingencies, making the total cost of the plane $32,825.45, while on the other hand twelve locks of 8 feet lift each would cost $198,000, a difference of $165,174.55 in favor of the plane. The other place I refer to as indicating the substitution of a plane for locks is at the month of Castleman River. The use of a plane at this point would save $102,243, as found above. These items of difference in cost aggregate $2,246,279.15, which is applicable to the reduction of the cost of the canal as estimated in my former report, reducing the cost from $19,937,285 to $17,691,006, a reduction of 11.25 per cent., a sum that, rated as an invested capital at 6 per cent. per annum, is equal to a saving of $134,776.75 in annual expense of maintaining the canal.

This character of inclined plane could also be applied on the Wills Creek section of the Wills Creek route under very similar conditions, as will be seen by reference to the report of the board of internal improvements, "eastern portion" of middle division, where the intervals between the locks are given as 180 yards, equal to 540 feet, and the average of six locks per mile obtains between Cumberland and the summit of the mountain.

Expenditure of water in operating the turbine motors.

In determining the work to be done in moving boats over the plane, the weight of the boat is taken at 30 tons, the weight of the cargo at 120 tons, and the carriage at 35 tons, making an aggregate load of 185 tons, or 414,400 pounds. Resolving this weight with reference to the plane rising 1 on 10, we have for the pressure perpendicular to the plane 412,343.4 pounds, and for the weight acting downward parallel to the plane, 41,234.34 pounds. This weight, together with the friction of the load, is to be overcome in moving the load up the plane. Taking the friction at eight pounds per ton of the weight normal to the plane, we have for the rolling friction 1,472.66 pounds, which gives the force to be applied in moving the load 42,707 pounds—moment pounds—parallel to the plane.

To raise the load one foot high, the travel along the plane will be 10.05 feet; and the corresponding foot-pounds will be 429,205.35. To move the boat at a rate of 2½ miles per hour, gives a rate of 3.60 feet per second, horizontal, or 3.685 feet along the plane, and the corresponding foot-pounds, are 157,375.44 pounds. As 550 foot-pounds are rated as one horse-power, we require 286.20 horse-power to move the load 3.685 feet in one second, or to raise it one foot high in one second. Adding five per cent. for friction of machinery, we get quite nearly 300 horse-power as the measure of work per second required for the turbine motor.

To determine the diameter of the turbine to do this work, and the quantity of water expended per second, in cubic feet, with a height of head of 64 feet, we have, by the formulas and proportions deduced from the Lowell hydraulic experiments, (by Mr. James B. Francis, C. E.,) for the diameter of the turbine 3.71 feet, and the water discharge 55.26 cubic feet per second. To move the carriage over the distance from the average place at the foot of the main plane until the rear wheels are over the crest of the planes toward the upper pool, whence the force of gravity will take it to the foot of that plane, a distance of 825 feet, will require 3.75 minutes' time and expend 12,433 cubic feet of water. [These formulas consider the useful effect of the turbine as 0.75 of that due to the hydraulic head.]

As turbines are so arranged that the expenditure of water is in proportion to the work done, we have an expenditure of 4,368 cubic feet of water to draw an empty boat, 65 tons, (with carriage,) up the plane, and to move the same loads from the upper pool over the crest of the plane, a distance of 200 feet, we have an expend ture of 3,014 cubic feet for a loaded boat, and 1,059 cubic feet for the empty boat. These quantities need not be necessarily fully expended, as a part of the work is done in moving the load over whatever distance the rear trucks of the carriage may be from the foot of the plane when the movement begins, and in carrying the rear trucks of the carriage over the crest of the plane, times in which the full power of the turbine is not required.

The movement of boats up or down the slopes of a canal, whether operated by planes or by locks, are somewhat analogous. When the canal is operated by locks each loaded boat passing up the canal draws from the upper pool one lock-full of water, plus the boat's displacement, and an empty boat one lock-full, plus its displacement; and in passing down the canal each boat draws off from the upper pool a lock-full of water less its displacement, when the locks are found empty; but if the locks are found full, the down-going boats will force the quantity of their displacement out of the locks into the upper pool. [A lock-full of water is considered as part of the lower pool.] In the case of the locks under consideration the prism of lift contains 12,000 cubic feet, and a loaded boat displaces its weight of 150 tons, 5,391 cubic feet, and an empty boat its weight of 30 tons, 1,078 cubic feet of water, and in making a comparison of the expenditure of water in the two systems of working the canal, the displacement of the downward-going boats will be credited for the case of finding full locks.

To make the conditions of comparison equable in the two systems, we will first consider the expenditure of water by four boats (two loaded and two empty) going up, and two loaded and two empty going down, giving the benefit of full locks to one loaded and one empty boat going down.

Direction and condition of boats.	Lock system.	Plane system.	Difference in favor of plane.
	Cubic feet.	*Cubic feet.*	*Cubic feet.*
Two loaded boats going up	34, 782	24, 866	9, 916
Two empty boats going up	26, 156	8, 736	17, 420
Loaded boat down, (lock empty)	6, 609	3. 014	3, 595
Empty boat down, (lock empty)	10, 922	1, 059	9, 863
Loaded boat down, (lock full)	5, 391	3, 014	2, 377
Empty boat down, (lock full)	1, 078	1, 059	19
Total for eight boats	72, 000	41, 748	....
Giving an average for each boat	9, 000	5, 218½	3, 781½

Showing a difference of 42 per cent. in favor of the inclined-plane system.

If, for a second comparison, we consider only loaded boats going in each direction, taking for example two boats each way, and giving one boat the benefit of finding a full lock going down, we find as follows:

Direction and condition of boats.	Lock expends.	Plane expends.	In favor of plane.
	Cubic feet.	*Cubic feet.*	*Cubic feet.*
Two loaded boats going up	34, 782	24, 866	9, 916
One loaded boat down, lock empty	6, 609	3, 014	3, 595
One loaded boat down, lock full	5, 391	3, 014	2, 377
Totals for four boats	36, 000	30, 894	....
Giving an average for each boat	9, 000	7, 724	1, 276

Showing a difference of 14 per cent. in favor of the inclined-plane system.

If we apply this method of comparison of the expenditure of water to the summit-level of the canal, we shall find, that when we consider the system of inclined planes, each loaded boat passing the summit draws off from the summit-level 15,447 cubic feet of water, and each empty boat 5,427 cubic feet of water, in the operation of the two summit-level planes, an average of 10,437 cubic feet to each boat; and if we take the case of the locks, each boat passing the summit, loaded or empty, draws off either 24,000 cubic feet or 12,000 cubic feet, as the lock by which the boat leaves the summit-level is found empty or full, an average of 18,000 cubic feet for each boat, a saving in the expenditure of water of 42 per cent. in favor of inclined planes. If we consider only loaded boats passing the summit we find for the inclined-plane system an expenditure of 15,447 cubic feet of water for each boat, and for the lock-system an average (again) of 18,000 cubic feet, or 14 per cent. in favor of the inclined plane. This is the best *practical* comparison that can be made in favor of the lock-system, and shows that the expenditure of water by this system of inclined planes is 86 per cent. of the expenditure by locks.

The most favorable assumption that can be made in favor of locks is that which presumes that the boats alternate in direction regularly and continuously day by day, and month by month, throughout the season, in which case each boat would expend but one lock-full of water in passing the summit-level; but this recurrence of boats is not presumable, and any derangement of this order for one day is not compensated by a similar disorder of recurrence on following days, and consequently presuming that two boats may go in one direction to one boat in the contrary direction, one and one-half locks-full of water are estimated to be expended by each boat passing the summit-level. This irregularity of directions of boats increases the expenditure of water at the summit by 50 per cent. in the lock-system, but with the system of inclined planes such irregularity in direction makes no change in the quantity of water expended at the summit, thus avoiding any doubt as to the supply required for a given number of boats, as each boat requires a given expenditure in passing the summit-level. In the case of locks, if twenty or thirty boats should pass the summit in the same direction and following each other they would each expend two locks-full of water, or more than double the quantity that would be expended by the same number of boats passing in the same order by the system of planes.

There is, however, a general condition of commercial transportation, which considered as a basis of comparison between these systems of operating the canal with especial regard to the expenditure of water in its daily operations, that gives great weight to the system of inclined planes.

The movement of freights between the East and the West, by the lines of transportation already established, shows that the freights eastward are greatly in excess of the freights westward, in the proportion of about 6 to 1. This indicates that about six loaded boats would go eastward to one loaded westward, that five-sixths of the boats going westward would be empty, and all going eastward would be loaded, consequently we may presume that of twelve boats passing the summit-level of the canal seven may be considered as loaded and five may be considered as empty. By the system of locks each boat passing the summit-level will have an average expenditure of 18,000 cubic feet of water or 216,000 cubic feet for the twelve boats, but by the system of inclined planes, the seven loaded boats will expend 108,129 cubic feet and the five empty boats will expend 27,125 cubic feet of water, a total of 135,254 cubic feet, an average of 11,271 cubic feet for each boat, or only 62 per cent. of the expenditure by locks. Upon this hypothesis of the movement of boats loaded and empty, the quantity of water required for operating the inclined planes may be determined definitely for any given number of boats, and generally the quantity of supply of feed-water at the summit may be determined upon the basis of tonnage per annum; 100 boats would carry (58 being loaded and 42 empty) 6,960 tons, and expend 1,137,117 cubic feet of water, about 162 cubic feet per ton, varying as the tonnage; whereas, on the contrary, by the lock-system the 100 boats passing the summit would expend equal quantities of water whether loaded or empty.

It may be further remarked that by the system of planes, the loss by leakage at the locks would be entirely obviated at the summit-level, an insignificant quantity probably, but yet worthy of being noted.

Referring again to the comparison of quantities of water expended at planes and at locks in the eastern slope of the canal, and applying the hypothesis of non-balance of freights eastward and westward, we find that six loaded boats passing eastward, and one loaded and five empty ones passing westward, will expend 52,357 cubic feet of water, and by the same movement of boats through a lock by the favorable condition of three eastward boats, finding full locks, there will be expended 73,357 cubic feet of water, nearly one-half more than the quantity expended by the inclined plane. This feature of the comparison, together with the absence of leakage at the summit-locks, shows that, in the system of inclined planes, the storage water in the summit-level is under better control in the matter of its distribution down the slope of the canal, saving in the last case 33 per cent. of the water expended by the system of locks, under the same condition of tonnage. This feature gives great weight to the system of inclined planes.

The local conditions in regard to these comparisons are, on the Savage River section of the canal, especially favorable to the system of inclined planes.

Effect on the tonnage capacity of the canal.

It was shown in my former report that the tonnage capacity of the canal is dependent on the facility of passing boats at the restricted points as at the locks, and was equal, under ordinary circumstances, to about eight boats per hour, and 192 per day. Upon the basis of moments of freights eastward and westward given above, seven-twelfths of these—112 boats—are loaded, aggregating a tonnage of 4,032,000 tonnage for a season of 300 days. In the case of the inclined planes, boats can be passed up (and down) over a distance of 950 feet in 4.4 minutes, allowing for time to get into the carriage, say ten boats per hour, increasing the capacity 25 per cent. With regard to the convenience of passing boats at a plane, it may be readily shown that they can be passed over the plane in one-half of the time, or in any other ratio, by the same expenditure of water, by increasing the power of the turbine motor.

If double-track planes were applied to the canal at the increased cost of 50 per cent., the capacity is to some extent unlimited, and ten boats could be passed in each direction in each hour, doubling the capacity last stated, which would give 480 boats per day, and 144,000 boats, 17,280,000 tons per annum of a season of 300 days.

Economy of time in transportation.

To determine the time of transit over a canal operated by locks, the time taken up in slowing up the boat to enter the lock, and the time taken up in getting under way again at the usual speed, must be taken into the account as the means of determining the time lost by retardation of speed, as well as the time required in locking through. A like amount of retardation takes place in passing a plane, as the boat must come very nearly to a dead stop in entering the carriage, but by good management the boat may be made to leave the carriage with the communicated velocity acquired in passing over the plane—2½ miles per hour.

[This is the practice on the Morris Canal.]

To determine the time consumed at locks in retardation and locking, we may take the operations on the completed canal as a basis. Under the most favorable conditions of the lock being open to an approaching boat, the tow-line is cast off at the distance of 350 feet from the lock, and the boat comes to a stop when in the lock, and we will assume that an equal distance is required to get under way again at the usual speed. The lock for this purpose is taken to be 120 feet long; and the distance occupied in slowing up, locking, and getting under way again is therefore 820 feet at each lock. The usual speed acquired over the canal between locks is two miles per hour, rarely faster. Loaded boats make the trip from Cumberland to Georgetown, a distance of 184.5 miles, in 4½ days, passing through 74 locks, making an average speed of 1.7 miles per hour.

The total distances taken to slow up, lock, and get under way are, for 74 locks, 60,680 feet, leaving 913,480 feet, over which the speed of two miles per hour is made, requiring 86½ hours of time, and the time remaining of 4½ days, 21½ hours, is taken up at the locks in retardation and locking, equal to $17\frac{4}{10}$ minutes at each lock, in passing over 820 feet of distance. To render this case somewhat more favorable, we will assume that but 15 minutes' time are taken up in slowing up, locking, and getting under way.

In applying these measures of time to the portion of the canal between Cumberland and Connellsville, via the Savage River route, we will consider it in characteristic section. Connellsville to mouth of Piney Run, 68 miles, with 134 locks; Piney Run to mouth of Savage River, 28 miles, with 156 locks; and Savage River to Cumberland, 31 miles, with 42 locks.

In passing over the first section of 68 miles, a boat will take up 33.5 hours in passing 134 locks, and 109,880 feet, leaving 249,160 feet to be passed over at the rate of two miles per hour, requiring 23.6 hours, a total of 57.1 hours for this section. On the middle section, deducting the tunnel summit-level of 5 miles length, which will be passed in 2.5 hours, 39 hours will be taken to pass 156 locks and 127,920 feet of distance, equal to 24.23 miles, 123 miles more than the distance to be passed over on this section, exclusive of the tunnel. The reason for this result is that the distances between the locks average about 660 feet, 40 feet less than is assumed to be taken up in getting under way, and slowing up to enter the next lock, and the boat does not get the speed of two miles per hour, as assumed, but in the half distance between locks will acquire a speed of 1.89 miles per hour. [As we have assumed nearly 2½ minutes less time at locks than was found by the basis of times on the portion of canal in operation, we may disregard this saving of a fraction of a minute.] The whole time on this section is 41.5 hours. The time occupied in passing over the section from the mouth of Savage River to Cumberland, we have 10.5 hours to 42 locks, and 34,440 feet of distance and 12.24 hours to pass over the remaining 129,240 feet or 24.48 miles, making for this section 22.74 hours, and for the whole distance between Cumberland and Connellsville, 121.34 hours, a rate of 1.05 miles per hour. If the 17.4 minutes found to be occupied at each lock had been used in these calculations the time would have been found to have been 13.28 hours more or 134.62 hours.

By system of inclined planes.

The time required for the passage of boats along the canal where inclined planes are used is to be determined in the same manner as for the system of locks. Equal times and distances are taken up in slowing up to enter the carriage, as in the case of locks, but no time is lost in retardation in getting under way again. If a boat, moving at the rate of two miles per hour, comes to a stop in 350 feet when the propelling power is stopped, the average rate of speed has been one mile per hour for the 350 feet of distance and the time 4 minutes, quite nearly. In the calculations for determining the expenditure of water in passing the plane, the rate of two and one-half miles per hour was assumed, and to pass from the upper to the lower pool or *vice versa*, a distance of, say, 990 feet, the time will be 4½ minutes, making 8½ minutes for the time taken at each plane to pass over a distance of 1,340 feet.

Considering first the section between the mouth of Piney Run and the mouth of Savage River, a distance of 28 miles, with 20 planes, we have for the time occupied at planes 2.83 hours and 26,800 feet of distance, and the remaining distance 22.92 miles is passed over in 11.46 hours, and the section is passed in 14.3 hours, (a saving in time of 27.2 hours on this section) with a rate of two miles per hour, quite nearly, the section being passed as if it were *one continuous unobstructed level.*

The saving of time at the other points named would be, at the mouth of Castleman River, difference between 2 hours at the eight locks in going over 6,520 feet and 8½ minutes and 29.4 minutes (37.9 minutes) to pass the same distance by the plane, a saving of 1.37 hours.

At the Ohio Pyle Falls, a plane of 96 feet lift would give a distance of 1,310 feet to be passed in 6 minutes, and 1,660 feet in 10 minutes, 12 locks would require 3 hours of time to 9,840 feet of distance, while in passing this distance with the plane, but 56½ minutes would be taken, saving here 2.06 hours; and the whole time that would be saved between Connellsville and Cumberland is 30 hours and 38 minutes, (equal to a shortening of the canal by 61.26 miles,) making the time from Connellsville to Cumberland 94 hours, only four days, and the average speed 1.35 miles per hour. If the time of passing locks as found by the operations of the canal in use, had been used, the saving in time would have been almost 4½ days.

It is quite probable that planes could be introduced at other places on the canal, but the surveys are not made in such detail as to determine this.

From the above discussion of planes and locks it is apparent that if planes of higher lift could be used, the economy of time and cost would be greater yet; and that were the canal operated to its full capacity with planes, the planes could be double-tracked at an increased cost not exceding 46 per cent. of the cost of the single-track planes, which would establish a double line of boats moving in opposite directions as fast as two miles per hour over the mountain section; nor would the double-track planes expend as much water in operating the turbines as would the single-track planes, because the load to be moved up or down the plane would be counterbalanced by 35 tons, or 60 tons, or 185 tons; and in all cases 33 per cent. of a saving in work would take place; and in the case of the movement of two boats at the same time, one or the other of the boats might be said to have been moved without any expenditure of water; and for the case of six loaded boats down, or eastward, and one loaded boat and five empty ones westward, on the Savage River section, if the boats could be moved over the planes in pairs the expenditure of water would be for the five empty boats up, and the one loaded one, 36,204 cubic feet, or an average of 2,901 cubic feet for each boat as compared with 4,363 cubic feet for each boat as found for the single-track plane, a saving, again, of nearly one half of the quantity estimated for the operation of single-track planes.

In the operations of the double-track plane, when two boats were to be moved at the same time, double work would have to be done in moving the boats over the length of the upper plane, and for this purpose a turbine of double the power figured for the single-track plane, would be required with double the expenditure of water for that time, and this double expenditure is considered in the calculation of the last average quantity of 2,901 cubic feet. Fixed caissons carrying water in which the boats may be floated while passing over the plane, have been used, as noted in the beginning of this report. Such an arrangement would add the weight of caisson to the load to be moved and also the weight of water required to float the boat, which would be an additional load of about 115 tons, and would require an additional expenditure of water in the same ratio for like movements of boats. In the case of a double-track plane with caissons, the same increase in expenditure of water would be necessitated; but in the case under discussion, that system of arrangement *must* be established that expends the least quantity of water.

In whatever manner the comparison may be made between the lock-system and the inclined-plane system, either of single locks and single-track planes, or of double locks and double-track planes, the economy in construction and in the expenditure of water is pre-eminently in favor of the inclined planes.

Stationary steam-engines could be substituted for the turbine motors, but their cost would be $15,000 additional at each plane. They would be more liable to accident, and require skilled superintendence and the constant expense of such, while, on the contrary, they would avoid the expenditure of water needed to operate the turbines.

Effect on cost of transportation.

Taking the operations of the completed canal between Cumberland and Georgetown as a basis of cost, a careful analysis of the cost of transporting coal shows a cost of 0.4 cents per ton per mile, exclusive of tolls, when the rate of transportation is 1.7 miles per hour, or at the rate of 0.68 cents per hour of time, and consequently a saving of 30½ hours' time works a saving of 20.8 cents per ton between Connellsville and Cumberland, an equated showing of 52 miles in distance by the system of inclined planes, in comparison with the system of lift-locks as herein compared.

Very respectfully,

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